# Enhancing Long Range Sonar Performance in Range-Dependent Fluctuating Ocean Waveguides by Mitigating Biological Clutter and Environmental Reverberation

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## LONG-TERM GOALS AND OBJECTIVES

Determine the temporal and spatial characteristics, and physical mechanisms for clutter and environmental reverberation in long range underwater acoustic imaging and surveillance systems. This understanding is used to develop operational and signal processing techniques to distinguish clutter from scattered returns due to man-man targets, and to determine the limits placed by environmental reverberation on target detection. In the second area, the statistical properties of broadband acoustic signals transmitted and scattered in range-dependent ocean waveguides are examined. This knowledge is then used to determine the extent to which environmental variabilities limit our ability to perform target localization and parameter estimation through beamforming and matched-filtering broadband data for imaging systems in fluctuating and dispersive ocean waveguides.

## APPROACH

The research effort involves developing and enhancing physics-based theoretical models for scattering from groups of fish, marine mammals and other biological organisms, multi-static scattering from extended targets, and environmental reverberation in *range-dependent* ocean waveguides. The data from the ONR-sponsored experiments in the Gulf of Maine in 2006 (GOME06) and in the New Jersey Strataform in 2003 (NJ03) measured with wide-area ocean acoustic waveguide remote sensing systems are processed and analyzed.

## WORK COMPLETED AND RESULTS

### 1. Statistics of Partially Saturated Broadband Ocean Acoustic Transmissions in a Shallow Water Waveguide

We have made significant progress in understanding the scintillation statistics of *broadband* ocean acoustic transmissions in a shallow water waveguide. We showed with data from GOME06 and NJ03 experiments that the fully saturated zero mean Gaussian random field assumption (*Makris JASA 1996, Dyer JASA 1970*) with uniform phase distribution, 5.6 dB intensity standard deviation and unity scintillation is applicable to short duration narrowband signals at sufficiently long ranges > 3km in a shallow water waveguide (Andrews et al. JASA 2009). For saturated broadband signals, their intensity standard deviations can be smaller than 5.6 dB due to averaging of uncorrelated frequency components or frequency coherence cells across the signal bandwidth (*Tran et al. JASA 2012*).

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE<br>**30 SEP 2013** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2013 to 00-00-2013** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Enhancing Long Range Sonar Performance in Range-Dependent Fluctuating Ocean Waveguides by Mitigating Biological Clutter and Environmental Reverberation** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**Northeastern University,360 Huntington Ave, 409 Dana Research Center,Boston,MA,02115** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **4** | |

At shorter ranges < 3km, both the narrowband and broadband acoustic signals are only partially saturated. One of our research goals is to quantify and determine the statistics of the partially saturated acoustic field in a shallow water waveguide. A stochastic ocean acoustic propagation model based on the parabolic equation has been implemented to model the acoustic field transmitted through a shallow water waveguide randomized by internal waves (*Andrews et al. JASA 2009*). Preliminary analysis with this model indicate the partially saturated time-harmonic complex acoustic field in a shallow water waveguide has a nonzero mean amplitude and a phase distribution that is highly asymmetric due to multi-modal composition of the acoustic field. As a result, the partially saturated narrowband complex field distribution cannot be depicted as a circular or elliptical cloud displaced from the origin in the complex plane, an assumption made in current standard models for the partially saturated ocean-acoustic field. The amplitude and phase distribution of the individual modes will be used to derive the resultant multipath amplitude, phase and intensity probability density functions (pdf) for the narrowband signal. We will then apply coherence theory to derive the pdf of the partially saturated broadband signal from that of the partially saturated narrowband signal.

Preliminary analysis of transmission data from GOME06 at short ranges approximately 45 to 60 m away from a source indicate the partially saturated narrowband signal has a significant nonzero mean field and a amplitude distribution that lies within an annulus offset from the origin. The partially saturated field amplitude distribution to be derived here will be compared to measured acoustic data in the range from 45 m to 3 km from a source array during GOME06. The derived amplitude distribution for the narrowband partially saturated field will be compared to the Rayleigh distribution and the Rician distribution which are the expected limiting forms for the amplitude distribution in the fully saturated (long range) and unsaturated but immersed in Gaussian random noise right next to the source regimes, respectively.

## 2. Testing passive source localization approaches for dense towed receiver array with significant ambient acoustic sources of opportunity

Approaches for instantaneous passive localization and tracking of acoustic sources over long ranges with measurements made on a single dense towed horizontal receiver array in a random range-dependent ocean waveguide have been examined (*Gong et al. JASA 2013*). An advantage of sensing with a dense horizontal array of hydrophones is that the bearing of the sound source can be directly obtained by beamforming the received signals so that only the range of the source to the receiver has to be determined. The methods implemented include (1) moving array triangulation (MAT) which combines measurements made on adjacent or widely separated finite apertures of a single towed receiver array and employs the conventional triangulation ranging algorithm for localizing sources located in the near- or far-field of the receiver array; (2) array invariant (AI), a technique that exploits the dispersive modal arrival structure of the acoustic field in an ocean waveguide to estimate the source range for sources located off the broadside beam of the receiver array; (3) the bearings-only target motion analysis in modified polar coordinates implemented using the extended Kalman filter (MPC-EKF) where the bearing and range components of the source location and velocity state vector are decoupled. All three methods were calibrated by applying them to determine the location and track of a source array in GOME06 with bearings-only measurement of the received field using a dense horizontal receiver array, the FORA array. The source localization accuracy is found to be highly dependent on source-receiver geometry and the localization approach. For a relatively stationary source drifting at speeds much smaller than the receiver array tow speed, the mean source position can be estimated by MAT with less than 3% error near broadside direction. For a moving source, the Kalman filter method gave the best performance with 5.5% error. The array invariant is the best approach for localizing sources within the endfire beam of the receiver array with roughly 7% error (*Gong et al. JASA 2013*).

During the ONR-funded spring 2013 sea test of a non-oil filled thin line towed receiver array, we opportunistically recorded several thousand sperm whale vocalizations in the Gulf of Maine shallow water waveguide and in the deep continental slope region south of Cape Cod. Using the sperm whale vocalized clicks as an acoustic source of opportunity, we tested the MAT algorithm by applying it to localize and track multiple sperm whales from bearings only measurement of the vocalization on a 32-element sub-aperture of the receiver array. The sperm whale locations were also independently estimated using the multiple reflection time of arrival (MR-TDA) differences of direct and multiple surface and bottom reflected click signals. The localization result using the two independent approaches are shown in Figure 1. The MAT technique gave smaller instantaneous localization error since the result is only dependent on whale bearing measurements. The MR-TDA technique on the other hand is dependent on both received signal arrival-time structure and also sensitively on the water depth and measurement geometry (*Tran et al. submitted to JASA 2013*). We believe this is the first time coherent array processing has been applied in sperm whale ranging. Our analysis indicates that it is possible to use a low frequency (~5kHz sampling frequency) dense towed receiver array system, such as those used in naval operations and geophysical exploration, to monitor sperm whales over wide areas spanning over 50 km in diameter.

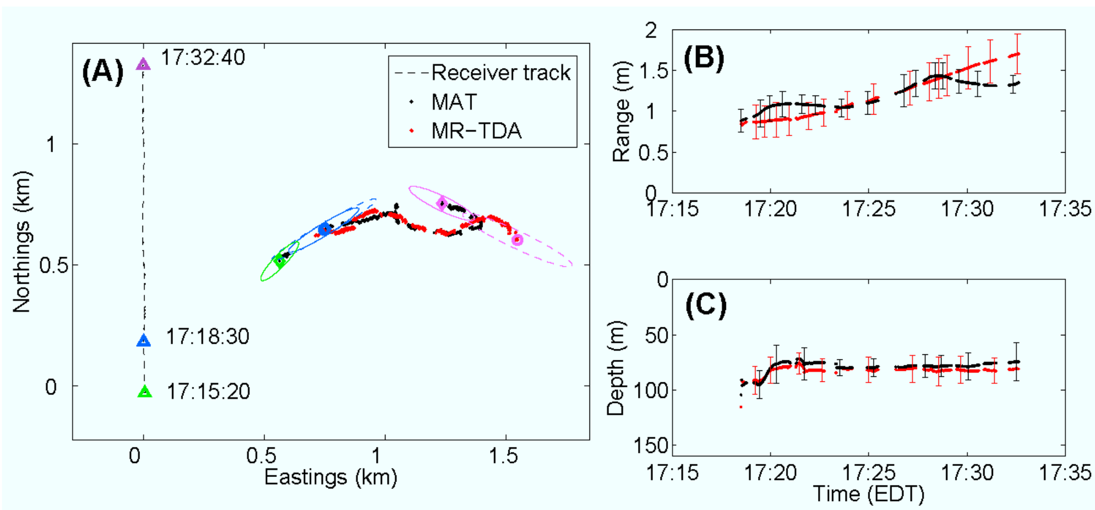


***Figure 1: Localization of a ambient sound source of opportunity. (1) A sperm whale in Gulf of Maine localized passively from its click signals using the two methods, MAT and MR-TDA for the period between 17:15:20 and 17:32:40 EDT on May 14, 2013. The ellipses represent contours of localization uncertainty at each time instance with MAT (solid curve) and with MR-TDA (dashed curve). (B) Range estimates using MAT and MR-TDA between 17:18:00 and 17:32:40 EDT. The errorbars show the standard deviation of the range estimates in a 4-minute time window. (C) Depth estimates for the same time period.***

### 3. Determining limits in sensing caused by biological ambient noise sources

Biological sources of sound can significantly dominate the ambient soundscape in many continental shelf regions of the US east and west coast. Chorusing sounds from fish groups have a broad spectrum, ranging over several hundred Hertz, that raises the overall background noise level in active and passive sensing for defence applications. Here we will quantify the spatial, temporal and spectral characteristics of fish chorusing sounds received on a high-resolution towed receiver array during the Gulf of Maine 2006 experiment which coincided with the Fall herring spawning season on Georges Bank. The ambient noise levels in the frequency band from 100 Hz to 2kHz are beamformed to determine their azimuthal dependence. The ambient noise levels in smaller subbands of width 100 Hz

are plotted in a polar diagram and tracked over time. The ambient noise levels in the azimuth of large fish shoals will be correlated to herring diurnal shoaling behavior. Preliminary analysis indicate that the fish may be passively detectable within a 200 to 300 Hz bandwidth. The chorusing levels will be quantified as a function of distance from the shoal. Transmission loss correction will be applied to determine the chorusing spectral source level.

## IMPACT/APPLICATIONS

We showed that broadband acoustic signals in shallow water undergo less fluctuations than monochromatic signals so that fewer measurements or smaller sample sizes are necessary to achieve desired accuracy in broadband active/passive sensing or communication applications.

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